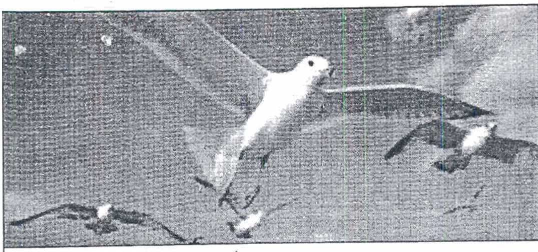
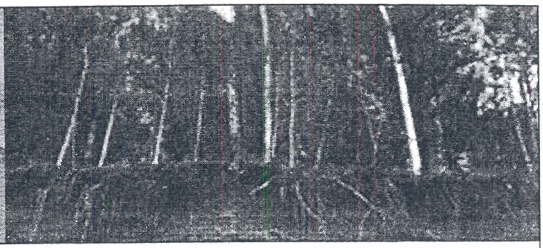
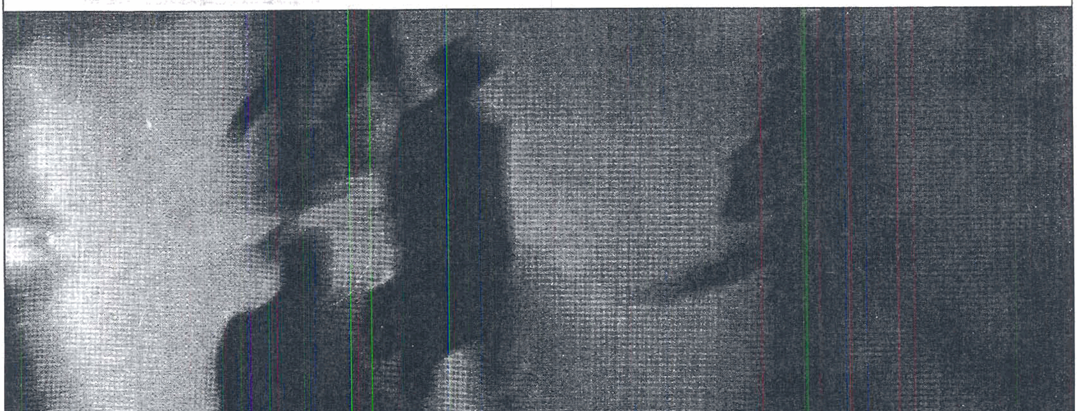



ECOSYSTEM FUNCTION & HUMAN ACTIVITIES

RECONCILING ECONOMICS AND ECOLOGY



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CHAPTER FOUR

Estuarine Ecosystem Issues on the Chesapeake Bay

Walter R. Boynton

Introduction

On a global basis, estuarine systems constitute a small percentage (~0.5 percent) of the world's oceanic areas. However, the very high fisheries production (~21 percent of world's catch), proximity to major urban areas and transportation networks, and the use of these areas for recreational purposes make them far more important than indicated by spatial extent alone (Houde and Rutherford 1993). In part because of the location of these systems at the margin between land and ocean, serious degradation has become widespread during the last few decades. If current demographic projections are correct, we should expect that human activities in the coastal zone will continue to intensify. In 1988, for example, the average population density in coastal counties in the northeast region of the United States (Maine to Virginia) was about 340 people per square mile; it is expected to increase by an additional 30 percent by 2010. Sediments, nutrients, and an array of toxic materials will probably find their way into these aquatic systems, leading to further declines in water quality, habitat conditions and living resources, especially if these areas do not have effective management programs (Culliton et al. 1990). In addition, increased human activities will intensify pressures on the habitats and living resources characteristic of these systems. In many systems, seagrass communities and other habitats have already been lost or degraded, tidal wetlands filled, and fish and shellfish stocks overfished or contaminated. In many ways, rapid and poorly designed development and other activities within adjacent drainage basins have destroyed or negatively impacted the very resources which were the prime reasons stimulating development in the first place. A key question, which includes both economic and ecological concerns, is how to manage these systems for sustainable outputs of inextricably coupled economic and environmental products and characteristics.

In Maryland and Virginia, much attention has focused for several decades on the Chesapeake Bay and its tributary rivers. In the 1950s, descriptive scientific information was gathered, species identified, life history patterns clarified and advances made concerning the physics of the system. In the 1960s, some of these activities were continued and others added but, of relevance here, the first indications of water quality deterioration were noted but largely ignored. It was not until the early 1980s that a strong consensus developed as to the major problems facing the Bay environment, and in the late 1980s remedial management actions were developed (Malone et al. 1994). In addition, it was not until the 1980s that serious attention was paid to activities in the watersheds that discharge into estuarine systems such as Chesapeake Bay and, as such, are the sources of many of the problems confronting Bay ecosystems. There remains today considerable debate about the most prudent ways to manage activities in the drainage basins.

The overall purpose of this paper is to present information concerning contemporary ecosystem issues in Chesapeake Bay. To accomplish this goal, some information concerning important estuarine ecosystem characteristics is presented to familiarize those not from the environmental sciences with central issues. Patterns of change during the last several decades in selected ecosystem characteristics are also presented and the cause-effect linkages responsible for these changes described. Finally, management actions designed to improve the general health of the Bay are described.

Some General Organizing Principles of Estuarine Ecology

Estuaries such as Chesapeake Bay are the ecosystems located on the margins that join continental lands with their surrounding seas. Estuarine ecosystems are coastal indentations that have "restricted connection to the ocean and remain open at least intermittently" (Day et al. 1989). In many of these ecosystems sea water is diluted by freshwater runoff from the land, but in regions where evaporation is high or rainfall low, estuarine salinities may be equal to or higher than those of the ocean. Most present-day estuaries were formed during the last 15,000 years of the current interglacial period, and are geologically recent features of the landscape (Day et al. 1989).

Because of the position of estuaries at the land-sea margin throughout the world, there is considerable diversity in estuarine types. Recognizing these differences is important because they influence the types of ecosystems that develop as well as the susceptibility of these systems to impacts from human activities. The most generally used classification of estuarine systems is based on geomorphology (Pritchard 1952) and includes the following types: (a) lagoons or bar-built estuaries (e.g. the coastal bays along the Maryland Atlantic coast), which are most often oriented parallel to the coast, tend to be shallow (often less than 2 meters in depth), and generally lack vertical stratification of the water column; (b) fjords, which result from glacial scouring, are generally deep (>100 m) and "U" shaped in cross-section, have strong vertical stratification and a sill or subsurface shoaling at the seaward end, which limits exchange with the ocean; (c) tectonically created estuaries (e.g. San Francisco Bay) which exhibit a variety of characteristics common to some of the other estuarine types; (d) coastal plain estuaries, which formed when river valleys became flooded after the last glaciation and have moderate water column stratification, broad shoal areas, and a moderately deep (–20–50 meters) central channel.

Chesapeake Bay is one of the best studied of the coastal plain type estuarine systems. Many of the basic characteristics of this system are well understood and have a direct bearing on ecological issues which are currently being confronted. One of the major, and perhaps unique, characteristics of the Chesapeake is the very large drainage basin compared to either the surface area or volume of the receiving waters (Fig. 4–1). One primary effect of this is that there is very little potential for dilution of pollutants to harmless concentrations. In engineering parlance, "dilution is not the solution to pollution," at least in the case of the Chesapeake system.

A second feature of overriding importance concerns water movement patterns or circulation of Bay waters. Figure 4–2 presents a generalized schematic of bay circulation, where freshwa-

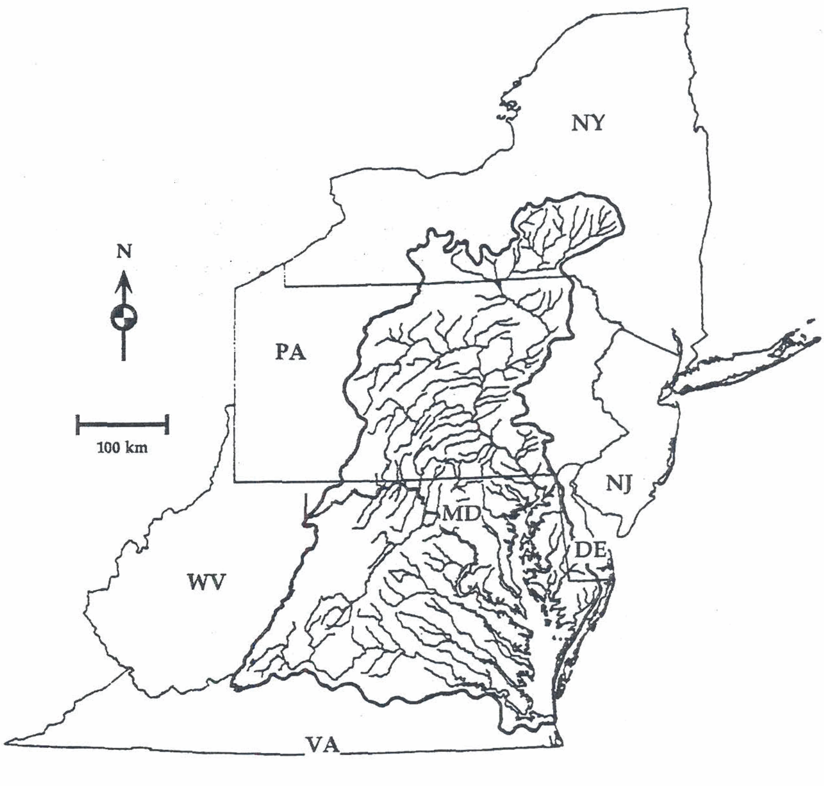

Figure 4–1. A regional view of Chesapeake Bay and its watershed showing the states encompassed and major portions of the tributary network. The ratio of drainage basin surface area to estuarine surface area is 28:1, indicating the potentially large impact of the land on this system. Inputs of water, nutrients, and organic matter are monitored at the fall-line of all the major rivers (representing 82 percent of the drainage basin); remaining loads are estimated using a land-use model.

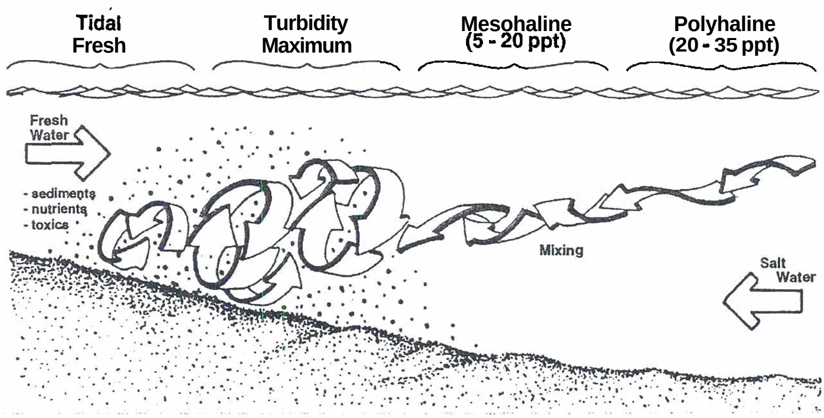

Figure 4-2. A simplified schemative diagram showing the main features of a two-layered estuarine circulation pattern. The major salinity zones along the estuarine salinity gradient are also shown. The bidirectional flow (seaward on the surface and landward on the bottom) acts to retain inputs which enter the system from the landward end. Numerous estuarine species have also adapted their life cycles to estuarine circulation patterns. For example, young blue crabs tend to stay in bottom waters when they are spawned near the ocean end and "ride" the up-estuary bottom water flow to the rich feeding grounds of the mesohaline and turbidity maximum regions. This diagram was adapted from Boicourt (1992).

ter from the drainage basin is shown entering on the left and moving toward the ocean as a surface water flow. To counter this seaward flow of freshwater, seawater moves into the bay as a near-bottom flow. This "gravitational circulation" is the net result of differences in pressure gradients which result from differences in the density of fresh and salt water (freshwater, being less dense than seawater, "floats" on top of the saltier bottom water). This bi-directional flow is characteristic of average conditions, but some degree of mixing occurs between the layers; mixing is more pronounced in some zones of the estuary (the turbidity maximum region) than in others (Fig. 4–2).

While there are many chemical and biological consequences due to this form of circulation, two are particularly important here. The first is that the vertical differences in density result in water column stratification, which in turn inhibits mixing of deep and surface waters. Despite the shallow nature of the Bay (mean depth –10 meters), stratification is a very effective barrier, particularly from spring through early fall of most years. As a result, deeper waters are not exposed to the atmosphere for long periods of time (–weeks-months) and can become very depleted in oxygen, in part because of stratification.

An important second feature is that two-layer circulation leads to relatively long retention times . . . in effect, what gets into the bay tends to stay in the bay. The freshwater fill times are on the order of a year, and this, coupled with the two-layer circulation pattern and relatively weak tides (<1 meter), results in a generally retentive system. As will be shown later, the fertilization rates for Chesapeake Bay are moderate compared to many other estuarine systems, but rates of both plant and animal production are very high, in part because essential nutrients which support these processes are retained in the Bay rather than rapidly transported to the coastal ocean. Obviously, the retentive characteristic of the bay system is both a blessing (high ecosystem production rates) and a curse (retention of pollutants).

Finally, the bay ecosystem is characterized by very substantial temporal and spatial variabilities. Important inputs to the bay (i.e. freshwater, sediments and nutrients) vary strongly throughout the year (~10×> in spring versus fall) and vary between years (>2×) as well. These pulsing inputs and interannual variations in turn influence both plant and animal production and spatial distributions of these creatures. As a result of these variabilities, it has been and continues to be difficult to separate clearly the influence of such things as normal climatic variability from human-induced changes to these ecosystems resulting from pollutant inputs (see Brush, this volume).

Major Ecosystem Issues of Chesapeake Bay

For the last 15–20 years, there has been intense debate which first focused on whether there were ecological problems associated with Chesapeake Bay, and more recently on what those problems were specifically and what could be done to correct damaged portions of the ecosystem. These debates continue to this day relative to some old and emerging issues. In fact, the list of real or suspected ecosystem issues concerned with Chesapeake Bay is large and would be much larger still if the drainage basin of the Bay were to be included in this discussion. In the context of this paper, only a few can be discussed. The three ecosystem issues listed below were selected because there is general agreement that these are real problems, they have seriously impacted portions of the Bay ecosystem, and the cause-effect linkages are more or less understood, allowing for potential remedial management actions.

Over-fertilization, Algal Blooms, and Oxygen Depletions

There is clear evidence that fertilization of the Bay with nitrogen and phosphorus began to increase shortly after European settlement, due mainly to land clearing. Coupled with this, there were changes in Bay plant communities. In the last several decades these changes have accelerated, and now large algal blooms are common in some regions of the Bay. Due to the decomposition of these algal blooms, dissolved oxygen concentrations in deep waters of the Bay have become depleted to very low levels during the late spring-early fall period. Dissolved oxygen depletions have become more severe and covered larger regions of the Bay and some tributaries in recent years. Regions of the Bay with low (<2 mg l^{-1}) dissolved oxygen conditions represent habitats that are not available to any of the animals commonly associated with productive estuarine food webs (Boicourt 1992).

Seagrass Decline

Prior to the early 1960s, the shoal waters of Chesapeake Bay were dominated by a diversity of submersed vascular plants. In the decade of the 1970s, ten or more species were virtually eliminated from this estuarine environment. Submersed plant communities contributed significantly to food production for Bay fish, invertebrates, and waterfowl populations, to habitats used by small animals for refuge from predation, to stabilization of sediment processes, and to the rapid and efficient cycling of important chemical elements (Kemp et al. 1984).

Fishery Declines and Failures

Because of the obvious economic values associated with commercial and recreational fisheries, considerable attention has focused on the status of these organisms. During the late 1970s and 1980s, one species (*Morone saxatilus*, striped bass) underwent a severe stock decline and persistent recruitment failure, but recently responded favorably to strong management actions. Fishery yields of American oysters (*Crassostrea virginica)* have declined to record low levels, and remaining stocks are being further depleted by mortality associated with two diseases. Additionally, stocks of an historically important anadromous species, American shad (*Alosa sapidissima*), have been very depressed for several decades due to a number of factors including blockage (due to dams) of streams leading to spawning areas, intense harvest pressures, and acidification of spawning streams.

Changes in Drainage Basin and Estuarine Characteristics

Qualitative reports of Chesapeake Bay made during the seventeenth century through the middle of the present century clearly indicate that bay habitats and living resources, in the forms of fish, shellfish, and water fowl, were indeed abundant and played an important role in the economy of the region and the ecology of Chesapeake Bay. For example, William Penn in the late 1600s noted the extreme abundance of seafood as well as the huge size of oysters in the Bay, and in 1884 annual oyster harvests reached an historic peak of 20 million bushels. The writer H.L. Mencken noted in 1940 that "Baltimore lay very near the immense protein factory of Chesapeake Bay, and out of it ate divinely."

In the last few decades reports concerning various fisheries and habitats of the Bay have not been as positive, and there have often been calls for drastic action to rehabilitate the living resources of the Bay. In addition, the habitat diversity of the Bay appears to have been greater prior to the last few decades. Some 13 species of submersed aquatic vegetation ringed the Bay shores from the tidal fresh rivers to the high salinity waters near the mouth of the Bay; the water column was reasonably clear with sunlight penetrating to several meters in most areas, and deeper in the more saline portions, and was sufficient to support nutritious benthic algal communities; oyster reefs provided important topographical relief on the broad shoals of the Bay; cooler and deeper waters in the natural channels of the Bay provided a refuge from high summer temperatures for a variety of finfish. In recent decades a considerable fraction of these habitats has been lost. While large efforts are currently underway to restore Bay fisheries and habitats, there have been serious losses of both during the post World War II period.

Watershed Characteristics

Despite the fact that the Bay is embedded in a relatively huge watershed (Fig. 4–1) that has been continually modified by human activities, the watershed approach (as it is now called) was not part of the general scientific thinking or management actions until the 1980s. *An* analysis of the history of water quality studies in the Chesapeake found only a few calls for consideration of watershed impacts on the Bay prior to the 1980s, but serious action was not started until the initiation of the multi-state EPA Chesapeake Bay Program and the results of scientific studies that clearly tied discharges from the land to water quality and habitat conditions in the Bay. Since then much has been written concerning changes in the watershed of the bay (see USEPA 1992 for detailed treatment of watershed modifications).

Changes in the Bay ecosystem are not solely recent phenomena but date back to at least the early portions of the Colonial period. Using various chemical and biological markers in the sediments of the Bay, Cooper and Brush (1991) were able to show that: sedimentation rates in the bay increased 5 to 7 fold after 1760 due to land clearing: occurrences of anoxic conditions became more common after 1940; and the diversity of diatoms (an important unicellular plant) has decreased and changed to favor planktonic as opposed to benthic (sediment) forms, presumably because the Bay has become more turbid and less light penetrates to the bottom (see also Brush, this volume).

In more recent decades, both population and land use in the Chesapeake basin have continued to change. For example, at the close of World War II the population of the basin was just over 5 million; growth was especially rapid between 1960 and the mid-1970s, a period corresponding to important indications of ecosystem stress and change in Chesapeake Bay ecology (Fig. 4–3a). Associated with population growth, land use changes were also occurring. Specifically, forested lands increased, agricultural lands decreased (especially pasture lands), and urban and residential lands expanded (Fig. 4–3b). While forested lands tend to conserve nutrients and sediments quite effectively, other land uses export nutrients to a far greater extent. With contraction of agricultural lands came more intensive use of remaining

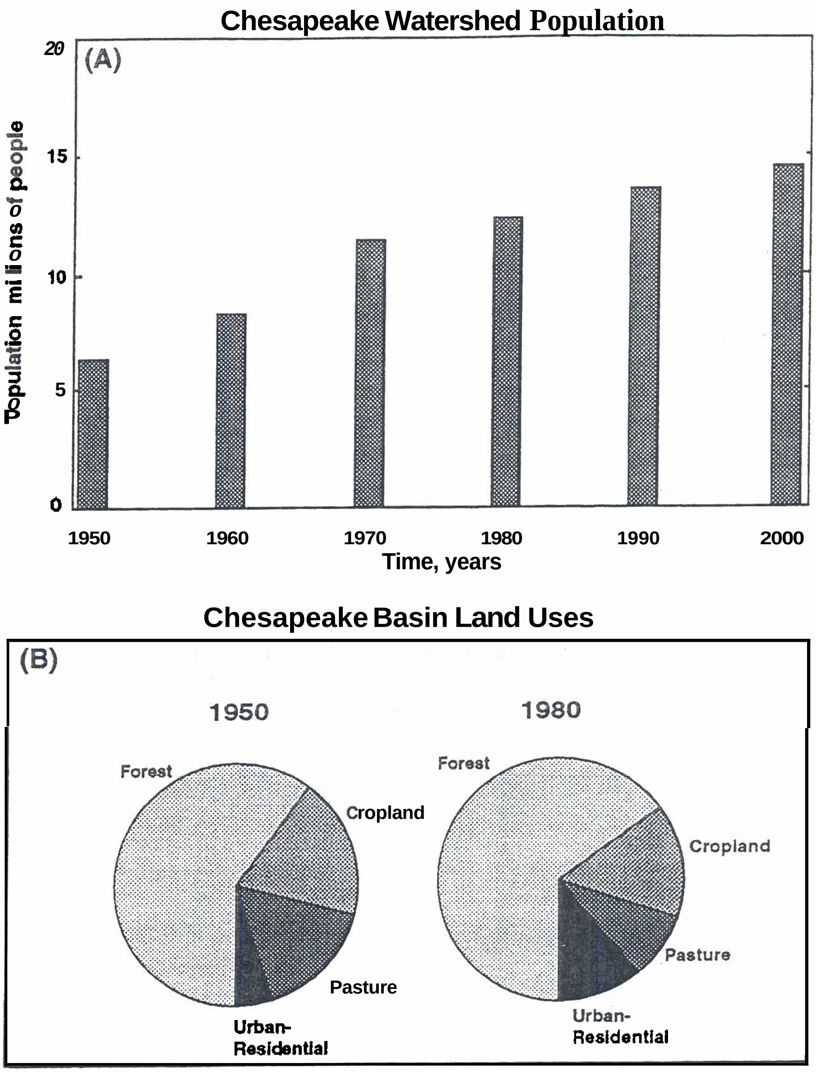

Figure 4–3. Summary of selected information concerning features of the Chesapeake drainage basin, including: (A) bar graph showing basin population from several different time periods (data are from USEPA 1992); (B) pie diagrams of land uses in the Chesapeake Bay drainage basin for two different time periods. Despite the increase in forested lands, nutrient loading rates for most portions of the Chesapeake system sharply increased in the period between 1950 and 1980. Since the late 1980s loads have decreased in some portions of the system and stabilized or increased only slowly in others (data are from USEPA 1983).

lands and of commercial fertilizers and pesticides, the use of which increased rapidly during the late 1960s and 1970s. The net effect of these changes in population and land use has been increasing loads of pollutants, especially nitrogen, phosphorus and sediments, to the Chesapeake Bay system.

Over-fertilization, Algal Bloom, and Oxygen Depletions

During the past few years, nutrient loading rates for a diverse mixture of ecosystems have appeared in the scientific literature, and it now seems safe to conclude that coastal systems have become among the most heavily fertilized of ecosystems because of increasing anthropogenic additions of nitrogen and phosphorus.

A few regions of Chesapeake Bay have been monitored for multiple decades, and in these areas it is possible to track changes in nutrient loading rates. In addition, it is possible to make crude estimates of what nutrient loading rates were at the time of initial European colonization of these systems and hence develop an estimate of pristine conditions, at least regarding nutrient loading rates (Table 4–1). In both the Patuxent and Potomac rivers, the historical record indicates increasing nitrogen inputs up to the present time; current loads exceed pristine loads by more than a factor of 5. Phosphorus loads also increased until the late 1970s and then decreased sharply in response to phosphorus removal at sewage treatment plants, a phosphate ban in detergents, and improved sediment erosion controls (phosphorus is readily transported via attachment to sediment particles). It is the goal of the Chesapeake Bay Program to reduce mid-1980s nutrient inputs by 40 percent by the year 2000.

Compared to other estuarine systems, nutrient loading rates to Chesapeake Bay are moderate to high for nitrogen and low to moderate for phosphorus. However, it is also clear that comparable nutrient loading rates in different ecosystems do not produce the same responses as those observed in the Bay. For example, nitrogen loading rates for the Potomac River and Narragansett Bay, Rhode Island are very similar, but poor water quality conditions extend throughout the mesohaline portion of the Potomac, whereas the analogous location is limited to a very restricted reach of upper Narragansett Bay (Magnien et al. 1990;

Table 4–1. A comparison of estimates of annual nitrogen and phosphorus inputs to several well studied tributaries of the Chesapeake Bay system. Loading rates for the pre-european period (prior to 1600) were made by using nitrogen and phosphorus release rates from mature forests not exposed to significant atmospheric deposition of nitrogen and phosphorus; estimates for other periods were based primarily on direct measurements. Data in the table are from Boynton et al. (1995).

		Annual Nutrient Loading		
Location	*Time Period*	*Total Nitrogen Load kg N x 10^6/yr*	*Total Phosphorus Load kg P x 10^6/yr*	*Reference*
Patuxent River	Pre-European	0.37	0.01	Boynton et al. 1995
	1963	0.91	0.17	Jaworski 1992
	1969–71	1.11	0.25	Jaworski 1992
	1978	1.55	0.42	Jaworski 1992
	1985–86	1.73	0.21	Boynton et al. 1995
Potomac River	Pre-European	4.6	0.12	Boynton et al. 1995
	1913	18.6	0.91	Jaworski 1992
	1954	22.6	2.04	Jaworski 1992
	1969–71	25.2	5.38	Jaworski 1992
	1977–78	32.8	2.51	Jaworski 1992
	1985–86	32.1	3.35	Lugbill 1990
	1985–86	35.5	2.93	Boynton et al. 1995

Nixon et al. 1986). On the other hand, loading rates to the Baltic Sea are much lower than those of most of the Chesapeake systems, but hypoxic and anoxic conditions are now characteristic of both (Larsson et al. 1985). Estuarine morphology, circulation, and regional climate conditions undoubtedly have strong influences on the relative impact of nutrient loading rates (Wulff et al. 1990).

In the Chesapeake Bay there is now strong evidence of the effects of increased nutrient fertilization, and in the last decade debate has been refocused from whether there were fertilization effects to how to achieve nutrient load reductions. One of the prime estuarine responses to nutrient fertilization is increased growth of phytoplankton, the unicellular plants that comprise the base of the food web. To a large extent, enhanced phytoplankton growth is analogous to the response of agricultural crops to fertilization. One of the most comprehensive evaluations of increased phytoplankton abundance in the Bay was developed by Harding (1994), who used both historical records of algal abundance and current aerial remote sensing data to develop a time series of observations covering four decades. In both the fresher and saltier regions of the Bay, there have been unmistakable increases in phytoplankton abundance which parallel increases in nutrient loading rates. Additional evidence for the linkage between nutrient loading rates and phytoplankton responses has been observed from data collected during the last decade of the Chesapeake Bay Monitoring Program; annual average phytoplankton abundance was strongly related to nutrient additions (Magnien et al. 1990).

The ecological effects of elevated phytoplankton abundance are of central concern. In the agricultural model, increased fertilization leads to larger crop yields and the overall effect is positive. However, in estuarine waters fertilization beyond a certain point initiates series of negative impacts, the results of which are propagated to varying degrees throughout the ecosystem. One of the initial effects occurs when abundant phytoplankton communities die and begin to decompose, mainly in the deeper waters of the Bay. In the process of decomposition, dissolved oxygen is consumed in large quantities and hypoxic (low oxygen) or anoxic (no oxygen) conditions result which are inhibitory or lethal to resident animal communities. It appears that the extent and duration of hypoxic conditions have increased since the 1950s (Cooper and Brush 1991). In addition, Boicourt (1992) has reported that the annual volume of hypoxic water in the Bay is a function of river flow; hypoxic volume increases as does river flow, due in part to the fertilization effect of the nutrients contained in river water and in part to the fact that the stratification of the Bay is proportional to river flow. In years of high flow, the resulting strong stratification prevents oxygen from the atmosphere from mixing into deep waters of the Bay and replenishing oxygen stocks depleted by decomposition of phytoplankton.

Seagrass Patterns

Submersed aquatic vegetation (SAV) communities play an important role in the functioning of shallow water portions of estuaries as well as in other aquatic ecosystems. Specifically, studies conducted over the last decade in estuarine systems indicate SAV communities maintain water clarity in shallow areas by binding sediments and baffling near-shore wave turbulence, modulate nutrient regimes by taking up nutrients in spring and holding these nutrients until fall, and enhance food-web production by supplying organic matter and habitat conducive for rapid growth of juvenile organisms. In much of Chesapeake Bay, SAV communities (which include some 13–15 species) started to undergo a serious decline during the 1960s in the upper portions of the Bay and in the early 1970s in the middle reaches of the Bay (Kemp et al. 1984). This decline was not taken seriously until the late 1970s, when a series of studies investigated potential causes. These experiments included field observations, small (50–700 liter) and large (400 cubic meters) microcosm exposure tests, and simulation modeling, and were conducted using several different plant species. Results indicated that the decline was primarily the result of nutrient over-enrichment. It appeared that epiphytic algae (a normal part of the SAV community) were over-stimulated by enhanced nutrient availability, which lead to increased shading of SAV leaves; photosynthetic rates of SAV were depressed below those needed for healthy plant growth. Increased water column turbidity and adhesion of suspended sediments to SAV leaves further reduced available light (Fig. 4–4). Herbicides were found to be a relatively small factor in the decline, although in areas of the Bay adjacent to agricultural drainage, seasonal herbicide stresses were possible (Kemp et al. 1984). It appears that if nutrient loading rates to these systems are reduced, SAV communities are capable of reestablishing themselves in many areas of the bay (Stevenson et al. 1993).

Selected Fishery Patterns

In the preceding portions of this paper, some of the more important changes in Chesapeake Bay ecology have been described; most have been negative. Before reaching the conclu-

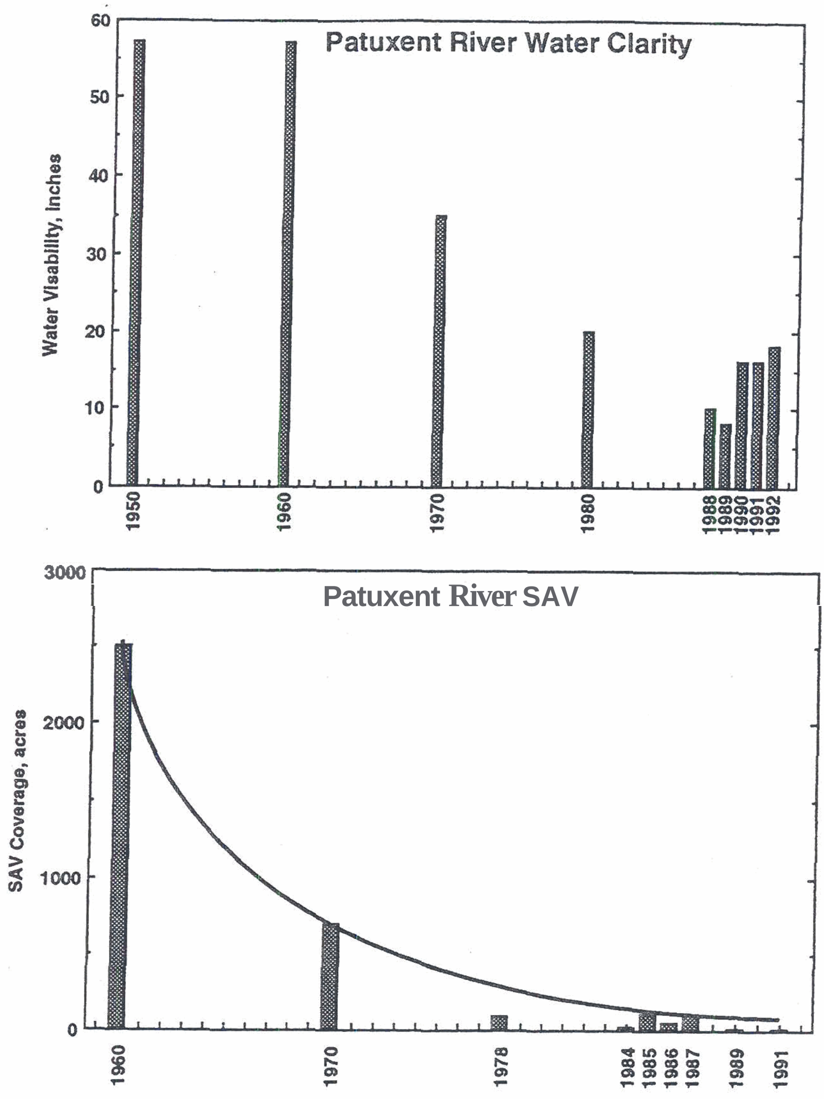

Figure 4–4. Historical patterns of water clarity and submerged aquatic vegetation (SAV) in the mesohaline zone of the Patuxent River estuary. Note that the rapid decline in SAV occurred during the decade of the 1960s, the same time period when the basin was undergoing large increases in population and changing land uses. Data are from U.S. Fish and Wildlife Service (1993).

sion that the Bay system is dead or close to it, we should be reminded that not all of the system is heavily impacted and that the degree of impact is worse in some years than in others. In fact, the Bay system is, as alluded to earlier, an immense protein factory. Data from a number of marine, coastal, and estuarine systems were organized by Nixon (1988) and explored for relationships between food production at the base of the food web (primary production) and fishery yields which depend on this production (Fig. 4–5). In this analysis, Chesapeake Bay is clearly a most productive system and furthermore appears to efficiently transfer organic material at the base of the food web to fisheries yields. Having said that not all is lost, there have been many changes in the status of commercially and recreationally important species in the Bay region since fishery statistics have been collected, and many of these changes have been negative.

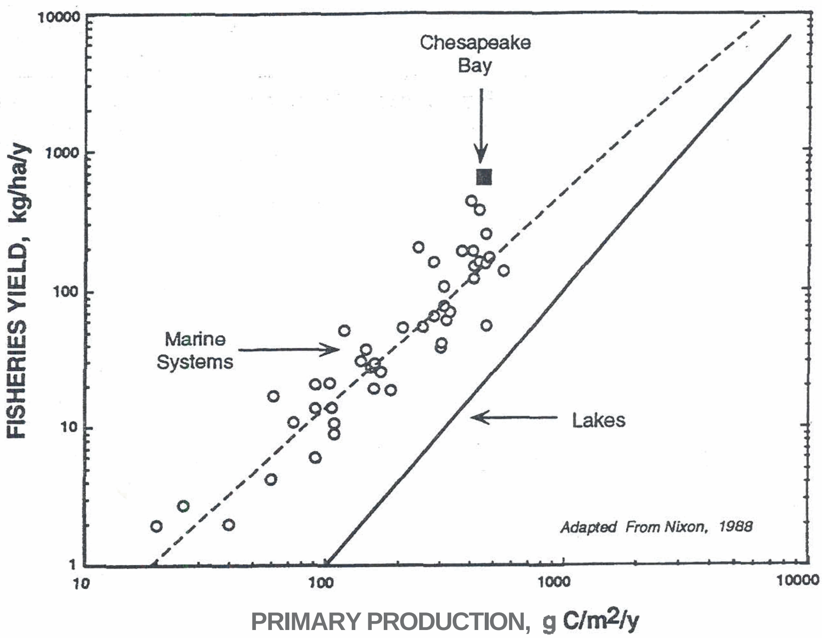

Figure 4-5. A scatter diagram showing relationship between primary production rates and fisheries yields for a variety of marine and estuarine ecosystems (open circles) and for a selection of lakes (summarized with the solid line). Chesapeake Bay is indicated by the bold square. The position of the Bay on the graph indicates that Bay food webs are particularly efficient in transfering food material into growth of commercial species. This figure was adapted from Nixon (1988).

The causes of these changes have been well established in some cases but remain unclear in others. In this section, an overview of recent trends of some of the most important fisheries of the bay is presented.

Striped Bass and American Shad The annual commercial catches of striped bass and American shad from both Virginia and Maryland and portions of Chesapeake Bay for the period 1929–1990 are shown in Figures 4–6a and 4–6c. In addition, an index of striped bass spawning success in Maryland waters is shown in Figure 4–6b. Striped bass catches underwent a multi-decade period of increase followed by a sharp decline in the last 15 years. At the present time, there is a relatively strict ban on striped bass fishing with only brief and highly regulated seasons in the spring and fall. Fishing for American shad is closed in the Bay and has been closed since the early 1980s, although fishing continues in waters of other coastal states. As with other commercially important species in the Bay, there is debate as to the most important causes of these declines. In the case of striped bass, reduction in spawning stock size (due to overfishing) and habitat degradation appear to be the most likely causes. The fishing ban on striped bass has yielded increased stock sizes, and 4–5 years after instituting the fishing ban, the regular pattern of successful recruitments every 2–4 years has started to reappear. There was a very successful striped bass recruitment in **1993** which is not shown in Figure 4–6b.

Despite the fact that the fishing ban on American shad has been in effect longer than the ban on striped bass, there is little indication that the stock has started to rebound, at least not to the degree observed for striped bass. One reason for this lack of response is that shad normally migrate much farther upstream than striped bass before spawning. Since virtually all tributary rivers of the Bay are dammed, it is generally assumed that blockage of access to optimal spawning areas has been a major factor impeding the re-establishment of this stock. In recent years fish ladders have been installed and operated in several important rivers, but the stock response has been small, suggesting that additional factors are also influencing recruitment. There are some data that suggest acid rain during the spring spawning season can depress pH in streams to levels lethal to shad larvae. In addition, the American shad fishing ban in Maryland does not apply to other coastal states; since shad spend a large percentage of their lives outside the Bay, they have been exposed to

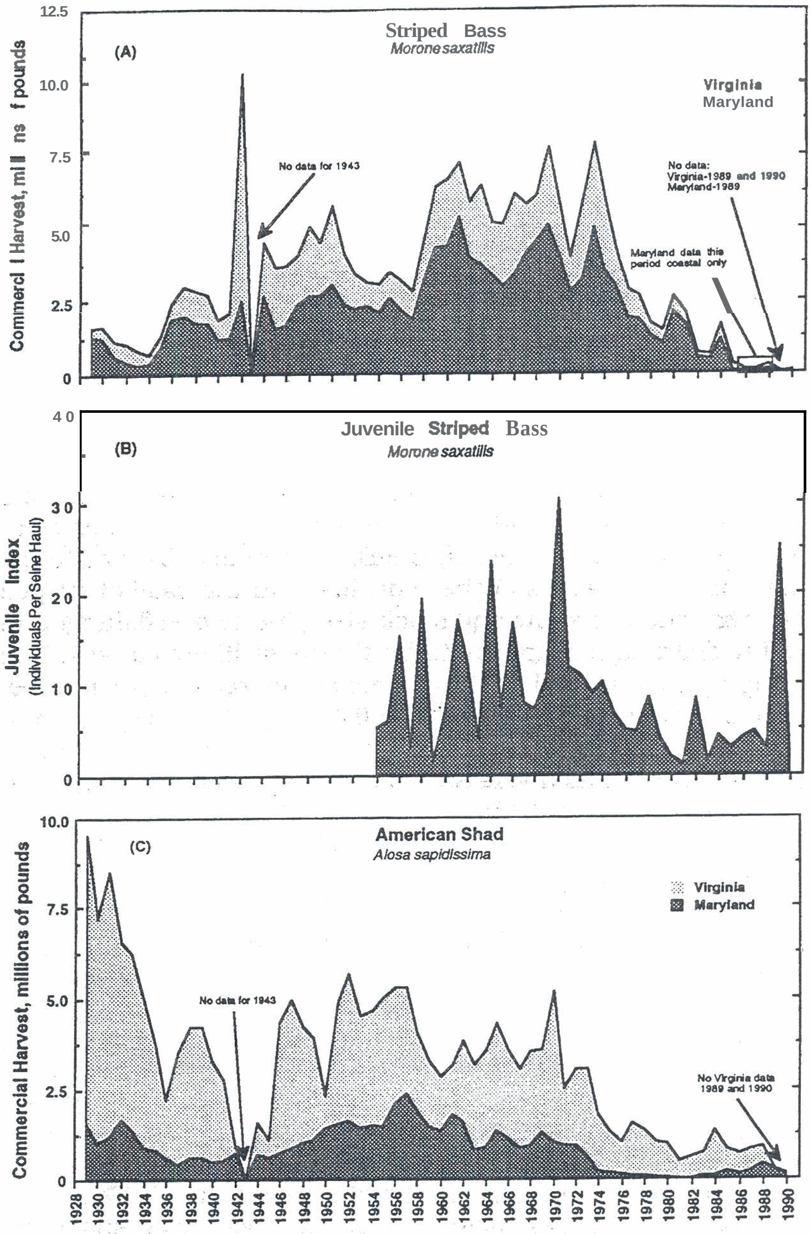

Figure 4–6. Annual commercial catches of striped bass (A) and American shad (C) from Maryland and Virginia waters between 1929 and 1990. Data are from Jones et al. (1990). Also shown is an index of striped bass spawning success (B) for the Maryland portion of the bay. Data are from Funderburk et al. (1991)

normal fishing pressure in these locations, and this may serve to inhibit stock rehabilitation.

American Oyster From 1929 through about 1960, combined Maryland and Virginia commercial oyster catches fluctuated between 20 and 40 million pounds per year. From 1960 through the early 1980s, combined catches decreased to 20–25 million pounds per year with virtually all of the decrease occurring in Virginia waters. However, there was a rapid decline in waters of both states beginning in 1981, and this trend has persisted and even intensified through the present time. There is considerable debate within the scientific, management, and fishing communities as to the relative importance of several factors in causing this decline, and there is equal if not more intense debate in management agencies concerning possible actions to rebuild this resource. Whatever management actions may eventually be taken, it appears that overfishing, disease, and loss of habitat have been the principle factors responsible for the decline of this resource.

Summary, Management Actions, and Ecosystem Responses

The major features of the ecosystem issues discussed above can be summarized in a simple cartoon diagram relating changing inputs of materials from the land to ecosystem outputs such as commercial fisheries (Fig. 4–7). In the diagram, nitrogen and phosphorus are shown entering the estuarine system and causing an increase in phytoplankton production and a decrease in light penetration due to shading by algae suspended in the water column. After nutrient supplies are exhausted by phytoplankton growth, the resultant blooms die and sink to the bottom, and oxygen is consumed in the decomposition of the bloom material. Hypoxic or anoxic conditions result, killing sessile organisms and removing the cooler deep waters as a habitat for fish communities. Nutrient enrichment also promotes the growth of algae on the leaves of SAV and limits the amount of light reaching the leaves: this light reduction, coupled with increased water turbidity, has been sufficient to kill SAV communities in many areas of the Bay. Again, SAV demise represents another loss of productive habitat in terms of a nursery and

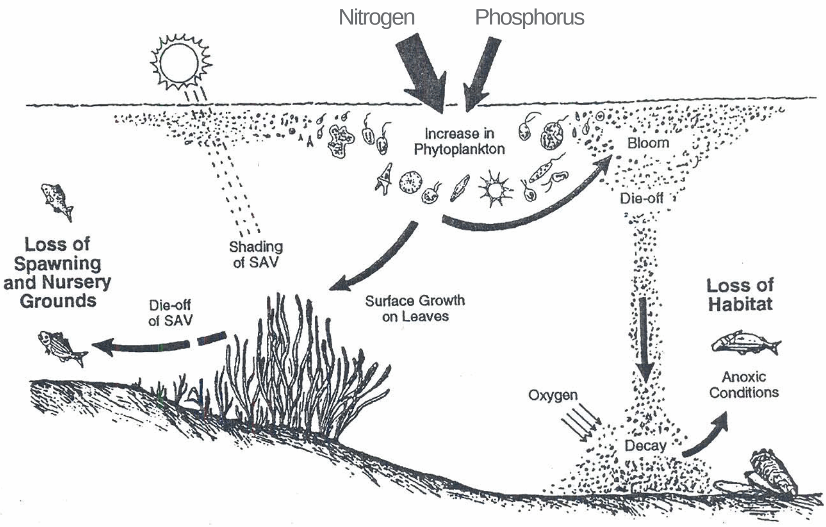

Figure 4–7. A cartoon diagram indicating the general cause-effect linkages of excessive nutrient (nitrogen and phosphorus) additions to estuarine ecosystems. When nutrient inputs become excessive, phytoplankton blooms occur and, after sinking to deep waters use large amounts of oxygen in decomposing. Excessive inputs also enhance algal growth on seagrass leaves leading to SAV die-off. Both the oxygen and SAV impacts represent serious habitat losses. This diagram was adapted from U.S. EPA (1983)

spawning area. Both of the habitat losses indicated in the diagram impact fisheries, but the quantitative relationships are not clearly established.

The Chesapeake Bay Program, which is a partnership between Bay states and the Federal government, has started on an ambitious program of bay restoration. The states are committed to reducing nutrient loads to the Bay by 40 percent by the year 2000; in several regions of the Bay, nutrient loads, particularly those associated with sewage treatment plant discharges, have already been reduced, and further reductions are planned. Most agree that control of diffuse sources of pollutants is the next big hurdle to be jumped and that this will be very difficult because of the dispersed nature of this nutrient source involving land use practices on private lands. Additional attention has been focused on nutrient additions from acid rain, which is a particularly important and only recently recognized source of pollution in the Bay region (Fisher and Oppenheimer 1991). Both the regional nature of the acid rain problem and the huge drainage basin of the Chesapeake make it clear that a regional, multistate approach to nutrient load reductions is necessary.

Studies have continued relative to SAV, and experimental planting programs indicate that the Bay grasses can be rehabilitated if nutrient loads are reduced (Stevenson et al. 1993). The experience agencies have had with the rehabilitation of the striped bass stock was particularly positive; a strong multi-state ban (or catch reductions) relieved fishing pressure to a point where the stock has started to successfully reproduce again. Management actions with other species have not been as successful, at least not to the present time. The disease problem with oysters appears to be particularly difficult to solve; this sector of the fishing industry is very depressed, and the path to rehabilitation is not clear. On a more positive note, there has been strong grassroots, state, and federal political support for improvements in the Bay environment, and because of this, it seems reasonable to expect that the search for solutions to Bay problems will continue and implementation of adequate pollution and fishing controls will lead to a healthier Chesapeake Bay,

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